

## **Data Communication over a Power Line**

### **Cross Reference to Related Applications**

This application claims priority under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Serial No. 60/268,519 and of U.S. Provisional Patent Application Serial No. 60/268,578, both filed February 14, 2001.

### **Field Of The Invention**

The invention generally relates to data communication over power lines and more particularly, to devices and methods for communicating data signals with the power lines.

### **Background Of The Invention**

A well-established power distribution system exists throughout most of the United States and other countries. The power distribution system provides power to customers via power lines. With some modification, the infrastructure of the existing power distribution system can be used to provide data communication in addition to power delivery. That is, data signals can be carried by the existing power lines that already have been run to many homes and offices. The use of the existing power lines may help reduce the cost of implementing a data communication system. To implement the data communication system, data signals are communicated to and from the power line at various points in the power distribution system, such as, for example, near homes, offices, Internet service providers, and like.

While the concept may sound simple, there are many challenges to overcome before using power lines for data communication. For example, a sufficient signal-to-noise ratio should be maintained, a sufficient data transfer rate should be maintained (*e.g.*, 10Mbps), "add on" devices should be installable without significantly disrupting power supply to power customers, "add on" devices should be designed to withstand outdoor conditions, bi-directional data communication should be supported, data communication system customers should be protected from the voltages present on power lines, and the like.

Power system transformers are one obstacle to using power distribution lines for data communication. Transformers convert voltages between power distribution system portions. For example, a power distribution system may include a high voltage portion, a medium voltage portion, and a low voltage portion and a transformers converts the voltages between these portions. Transformers, however, act as a low-pass filter, passing low frequency signals (e.g., 50 or 60 Hz power signals) and impeding high frequency signals (e.g., frequencies typically used for data communication) from passing through the transformer. As such, a data communication system using power lines for data transmission faces a challenge in passing the data signals from the power lines a to customer premise.

Moreover, accessing data signals on a power lines is a potential safety concern. Medium voltage power lines can operate from about 1000 V to about 100 kV which can generate high current flows. As such, any electrical coupling to a medium voltage power line is a concern. Therefore, a need exists for a device that can safely communicate data signals with a medium voltage power line and yet provide electrical isolation from the medium voltage power line.

In addition to communicating a data signal with a medium voltage power line, it would be advantageous to communicate the data signal to a low voltage power line for data distribution to a customer premise. That is, a need also exists for a device that electrically communicates a data signal between a medium voltage power line and a low voltage power line, while maintaining electrical isolation between the medium voltage power line and the low voltage power line.

### **Summary Of The Invention**

The invention is directed to communicating data signals over a power line. A signal is received from a first portion of the power line and at least a portion of the signal is converted to a non-electrically conducting signal. The non-electrically conducting signal may be communicated to a non-electrically conductive communication path. In this manner, the non-electrically conducting signal may have properties that do not provide imminent danger from human contact.

The signal may be received inductively from the power line. The signal may include a data component and a power component and the power component may be filtered from the data component. The filtering may be inductive, capacitive, digital, and the like.

The non-electrically conducting signal may be a light signal, a radio frequency signal, an electromagnetic signal, and the like. The non-electrically conductive communication path may include an optic fiber, a dielectric material, an antenna, air, and the like.

The non-electrically conducting signal may be communicated to a second portion of the power line, to a telephone line, to air, to a fiber optic cable, and the like. The non-electrically conductive signal may be modulated, demodulated, and routed.

An apparatus for communicating data over a power line includes a coupling device that receives a signal from the power line and a signal conversion device that converts the signal to a non-electrically conducting signal.

The coupling device may be an inductor. The inductor may include a toroidally shaped coil and a toroidally shaped core of magnetically permeable material. Dielectric material may be disposed proximate the core. The inductor may be hinged for mechanical attachment to the power line.

The signal conversion device may include an optoelectronic transceiver, a light-emitting diode, a laser, a vertical cavity surface emitting laser, a photosensitive diode, a photosensitive transistor, and the like.

The apparatus may include a filtering device that filters a power component of the signal from a data component of the signal. The filtering device may include a capacitor.

The apparatus may include a power supply electrically coupled to the signal conversion device. The power supply may include a toroidally shaped coil having a magnetically permeable core.

The apparatus may be a portion of a system for communicating data over a power line, wherein the system further includes a communication interface device that receives the non-electrically conducting signal and interfaces the signal to a second communication path. The second communication path may be a second portion of the power line, a telephone line, air, a fiber optic cable, and the like.

The communication interface device may include a modem and a data router. The communication interface device may include a second signal conversion device and a second coupling device.

The above-listed features, as well as other features, of the invention will be more fully set forth hereinafter.

**Brief Description Of The Drawings**

The invention is further described in the detailed description that follows, by reference to the noted drawings by way of non-limiting illustrative embodiments of the invention, in which like reference numerals represent similar parts throughout the drawings. As should be understood, however, the invention is not limited to the precise arrangements and instrumentalities shown. In the drawings:

Figure 1 is a diagram of an exemplary power distribution system with which the invention may be employed;

Figure 2 is a diagram of the exemplary power distribution system of Figure 1 modified to operate as a data communication system, in accordance with an embodiment of the invention;

Figure 3 is a block diagram of a portion of a data communication system, in accordance with an embodiment of the invention;

Figure 4 is a block diagram of a portion of a data communication system, in accordance with an embodiment of the invention;

Figure 5 is a perspective view of a power line coupler and a power line bridge installed at a telephone pole of a power distribution system, in accordance with an embodiment of the invention;

Figure 6 is a schematic of a power line coupler, in accordance with an embodiment of the invention;

Figure 7 is a schematic of another power line coupler, in accordance with another embodiment of the invention;

Figure 8 is a diagram of another portion of a data communication system, in accordance with another embodiment of the invention; and

Figure 9 is a flow diagram of an illustrative method for data communication over a power line, in accordance with an embodiment of the invention.

**Detailed Description Of Illustrative Embodiments**

A power line coupler and a power line bridge communicate data signals across a transformer that would otherwise filter the data signals from passing through the transformer. Further, the power line coupler provides high electrical isolation between the transformer primary side and secondary side, thereby preventing substantial power flow through the power line coupler and the power line bridge. It should be appreciated that the

functionality of the power line coupler and the power line bridge can be included in one device or distributed in more than one device. The power line coupler may include a power line coupling device that communicates data signals with a power line, circuitry to condition the data signal, circuitry to handle bi-directional signal transfer, circuitry to enable the use of an electrical isolator, circuitry to provide operational power from the power line, and may be designed to be self-contained. The power line coupler may include circuitry to communicate with the power line coupler and circuitry to convert data signals to a second format for communication to a customer premise.

An exemplary power distribution system is shown in Figure 1. As shown in Figure 1, power distribution system 100 is a medium voltage half loop power distribution system that is common to the United States. The invention, however, may be employed with other power distribution systems, such as, for example, a high voltage delivery system that is common to European countries, as well as other power distribution systems.

Power distribution system 100 includes components for power generation and power transmission and delivery. As shown in Figure 1, a power generation source 101 is a facility that produces electric power. Power generation source 101 includes a generator (not shown) that creates the electrical power. The generator may be a gas turbine or a steam turbine operated by burning coal, oil, natural gas, or a nuclear reactor, for example. Power generation source 101 typically provides three-phase AC power. The generated AC power typically has a voltage as high as approximately 25,000 volts.

A transmission substation (not shown) increases the voltage from power generation source 101 to high-voltage levels for long distance transmission on high-voltage transmission lines 102. Typical voltages found on high-voltage transmission lines 102 range from 69 to in excess of 800 kilovolts (kV). High-voltage transmission lines 102 are supported by high-voltage transmission towers 103. High-voltage transmission towers 103 are large metal support structures attached to the earth, so as to support the transmission lines and provide a ground potential to system 100. High-voltage transmission lines 102 carry the electric power from power generation source 101 to a substation 104.

In addition to high-voltage transmission lines 102, power distribution system 100 includes medium voltage power lines 120 and low voltage power line 113. Medium voltage is typically from about 1000 V to about 100 kV and low voltage is typically from about 100 V to about 240 V. As can be seen, power distribution systems typically have different voltage portions. Transformers are often used to convert between the respective

voltage portions, e.g., between the high voltage portion and the medium voltage portion and between the medium voltage portion and the low voltage portion. Transformers have a primary side for connection to a first voltage and a secondary side for outputting another (usually lower) voltage. Transformers are often referred to as a step down transformers because they typically “step down” the voltage to some lower voltage. Transformers, therefore, provide voltage conversion for the power distribution system. This is convenient for power distribution but inconvenient for data communication because the transformers can degrade data signals, as described in more detail below.

A substation transformer 107 is located at substation 104. Substation 104 acts as a distribution point in system 100 and substation transformer 107 steps-down voltages to reduced voltage levels. Specifically, substation transformer 107 converts the power on high-voltage transmission lines 102 from high voltage levels to medium voltage levels for medium voltage power lines 120. In addition, substation 104 may include an electrical bus (not shown) that serves to route the medium voltage power in multiple directions. Furthermore, substation 104 often includes circuit breakers and switches (not shown) that permit substation 104 to be disconnected from high-voltage transmission lines 102, when a fault occurs on the lines.

Substation 104 typically is connected to at least one distribution transformer 105. Distribution transformer 105 may be a pole-top transformer located on a utility pole, a pad-mounted transformer located on the ground, or a transformer located under ground level. Distribution transformer 105 steps down the voltage to levels required by a customer premise 106, for example. Power is carried from substation transformer 107 to distribution transformer 105 over one or more medium voltage power lines 120. Power is carried from distribution transformer 105 to customer premise 106 via one or more low voltage lines 113. Also, distribution transformer 105 may function to distribute one, two, three, or more phase currents to customer premise 106, depending upon the demands of the user. In the United States, for example, these local distribution transformers typically feed anywhere from one to ten homes, depending upon the concentration of the customer premises in a particular location.

Transformer 105 converts the medium voltage power to low voltage power. Transformer 105 is electrically connected to medium voltage power lines 120 on the primary side of the transformer and low voltage power lines 113 on the secondary side of the transformer. Transformers act as a low-pass filter, passing low frequency signals (e.g., 50 or

60 Hz power signals) and impeding high frequency signals (e.g., frequencies typically used for data communication) from passing from the transformer primary side to the transformer secondary side. As such, a data communication system using power lines 120 for data transmission faces a challenge in passing the data signals from the medium voltage power lines 120 to customer premises 106.

Figure 2 illustrates the power distribution system of Figure 1 as modified for operation as a data communication system, in accordance with an embodiment of the invention. As described above, a power distribution system is typically separated into high voltage power lines, medium voltage power lines, and low voltage power lines that extend to customer premises 106. The high voltage power lines typically have the least amount of noise and least amount of reflections. These high voltage power lines have the highest potential bandwidth for data communications. This is convenient because it is the portion that concentrates the bandwidth from the other low and medium voltage portions. The type of signal modulation used on this portion can be almost any signal modulation used in communications (Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA), Frequency Division Multiplex (FDM), Orthogonal Frequency Division Multiplex (OFDM), and the like). Typically, OFDM is used on both the low and medium voltage portions. A modulation producing a wideband signal such as CDMA that is relatively flat in the spectral domain may be used to reduce radiated interference to other systems while still delivering high data communication rates.

Medium voltage power lines 120 and low voltage power lines 113 typically have some noise present from electrical appliances and reflections due to the "web" of wires in those portions. Low power voltage lines 113 often have more noise than medium voltage power lines 120. These portions of the power distribution system typically support a lower bandwidth than the high voltage power lines and therefore, usually employ a more intelligent modulation scheme (typically with more overhead). There are several companies with commercially available chip sets to perform modulation schemes for local area networks (LANs) such as, for example: Adaptive Networks (Newton, Mass), Inari (Draper, Utah), Intellion (Ocala, FL), DS2 (Valencia, Spain) and Itran (Beer-Sheva, Israel).

As shown in Figure 2, a power line coupler 200 communicates with medium voltage power line 120 and a power line bridge 210 communicates with low voltage power line 113. Further, power line coupler 200 and power line bridge 210 communicate with each other to allow data signals to bypass transformer 105, as described in more detail below. A

power line interface device 250 can plug into an electrical outlet and operates to allow customers to access the data signal on the low voltage power line 113. An aggregation point 220 operates to allow a service provider to access data signals on medium voltage power line 120. It should be appreciated that although power line coupler 200 and power line bridge 210 are shown in Figure 2 as being located at a specific location, the power line coupler and the power line bridge functionality may be located in various locations on the power system..

Returning to power line coupler 200 and power line bridge 210, Figure 3 illustrates an example of their operation. As described above, bridging data signals between portions of the power distribution system can be a problem, because of the low pass filtering aspect of a transformer. To overcome the problem, power line coupler 200 and power line bridge 210 form an electrically non-conductive path 300 for communicating non-electrically conducting signals around transformer 105, thereby bypassing the low-pass filtering of transformer 105. While electrically non-conductive path 300 does not pass significant amounts of power, it does allow data signals to bypass transformer 105. That is, power line coupler 200 interfaces data signals to medium voltage power lines 120 on the primary side of transformer 105 and power line bridge 210 interfaces data signals to low voltage power lines 113 on the secondary side of transformer 105.

Power line coupler 200 and power line bridge 210 communicate with each other, thereby allowing data signals to bypass transformer 105, thus avoiding the filtering of the high frequency data signal that otherwise would occur in transformer 105. Lower frequency power signals continue to flow from medium voltage power lines 120 to low voltage power lines 113 via transformer 105. Power line coupler 200 provides electrical isolation between medium voltage power lines 120 and low voltage power lines 113 by substantially preventing power from flowing over electrically non-conductive path 300.

Figure 4, illustrates more detail of power line coupler 200 and power line bridge 210. As shown in Figure 4, power line coupler 200 includes a power line coupling device 400 and an electrically non-conductive device 410.

Power line coupling device 400 communicates data signals with medium voltage power line 120. Power line coupling device 400 may include, for example, a current transformer, an inductor, a capacitor, an antenna, and the like.

Electrically non-conductive device 410 provides electrical isolation between medium voltage power lines 120 and low voltage power lines 113 and communicates non-electrically conducting signals. Electrically non-conductive device 410 may be a fiber optic



cable, a light pipe, a sufficiently wide air gap, a sufficiently wide dielectric material, and the like.

Power line bridge 210 may include a modem 420, a data router 430, a modem 440, an electrically non-conductive device 450, and a power line coupling device 460.

Modem 420 modulates and demodulates data signals between power line coupler 200 and data router 430. Modem 420 typically is selected to optimize the communication of the data signals over medium voltage power line 120. For example, modem 420 may be selected to operate with a 50 MHz carrier frequency. Further, modem 420 may be selected to use a modulation technique, such as, for example, CDMA, TDMA, FDM, OFDM, and the like.

Router 430 routes digital data signals between modem 420 and modem 440. Router 430 may receive and send data packets, match data packets with specific messages and destinations, perform traffic control functions, perform usage tracking functions, authorization functions, throughput control functions, and the like.

Modem 440 modulates and demodulates data signals between power line coupler 460 and data router 430. Modem 440 typically is selected to optimize the communication of the data signals over low voltage power line 113. Modem 440 may be selected to operate with a carrier frequency within the range of 2 to 24 MHz, for example. Further, modem 420 may be selected to modulate using a technique, such as, for example, CDMA, TDMA, FDM, OFDM, and the like. The use of modems 420 and 440 allows the modulation technique for each modem to be individually matched to the characteristics of the power line with which it communicates. If however, the same modulation technique is used on both low voltage power lines 113 and medium voltage power lines 120, modem 420, data router 430, and modem 440 may be omitted from power line bridge 210.

Electrically non-conductive device 450 provides electrical isolation between low voltage power lines 113 and modem 440. Electrically non-conductive device 450 may be a fiber optic cable, a light pipe, a sufficiently wide air gap, a sufficiently wide dielectric material, and the like. Because low voltage power lines 113 operate at a low voltage, electrically non-conductive device 450 may include a capacitor. That is, a capacitor can provide a sufficient electrical isolation between low voltage power lines 113 and a customer. Power line coupling device 460 may include a current transformer, an inductor, a capacitor, an antenna, and the like.

Figure 5 illustrates an installation of power line coupler 200 and power line bridge 210 to a power distribution system. As shown in Figure 5, power line coupler 200 is mounted proximate medium voltage power line 120 and power line bridge 210 is mounted proximate low voltage power line 113. Power line coupler 200 and power line bridge 210 are in communication via communication medium 500. Communication medium 500 may be a fiber optic cable, an air gap, a dielectric material, and the like.

Power line coupler 200 receives a data signal from medium voltage power line 120. Power line coupler 100 converts the data signal to a non-electrically conducting signal (*i.e.*, a signal that can be transmitted over a non-electrically conductive path). A non-electrically conducting signal may be a light signal, a radio frequency signal, a microwave signal, and the like. Power line coupler 200 transmits the signal over communication medium 500. Power line bridge 210 receives the non-electrically conducting signal and conditions the signal for communication over low voltage power line 113 to customer premise 106 (as discussed with reference to Figure 2).

Rather than communicating data signals to customer premise 106 via low voltage power line 113, power line bridge 210 may use other communication media. Figure 5 depicts several other techniques for communicating data signals to customer premise 106. For example, power line bridge 210 may convert the data signals to electric data signals and communicate the electric data signals via telephone line 550 or coaxial cable line 554. Such communication may be implemented in a similar fashion to the communication with low voltage power line 113.

Power line bridge 210 may convert the data signal to radio signals for communication over a wireless communication link 556. In this case, customer premise 106 includes a radio transceiver for communicating with wireless communication link 556. In this manner, power line bridge 210 functions as a communication interface, converting the non-electrically conducting signal to a signal appropriate for communication to customer premise 106. Wireless communication link 556 may be a wireless local area network implementing a network protocol in accordance with the IEEE 802.11 standard.

Alternatively, light signals may be communicated to customer premise 106 directly via a fiber optic 552. In this alternative embodiment, power line bridge may convert the data signals to light signals for communication over fiber optic line 552. Alternatively, the data signals already may be in light form and therefore, power line coupler may communicate directly with user premise 106. In this embodiment, customer premise 106

may have a fiber optic connection for carrying data signals, rather than using the internal wiring of customer premise 106.

Figure 6, illustrates more details of power line coupler 200. As shown in Figure 6, power line coupler 200 includes an inductor 602, capacitors 606, transmit circuitry 610, receive circuitry 612, transmit optoelectronic device 620, and receive optoelectronic device 622.

Inductor 602 communicates data signals with medium voltage power line 120 via magnetic coupling. Inductor 602 may be a toroidally shaped inductor that is inductively coupled with medium voltage power line 120. Inductor 602 includes a toroidally shaped magnetic core with windings 604 disposed to facilitate flux linkage of the data signal on medium voltage power line 120. The number and orientation of windings 604 typically is selected for increased flux linkage. Further, the permeability of the magnetic core typically is selected for high coupling with the high frequency data signal and a high signal to noise ratio. Also, the permeability characteristics of inductor 602 may be selected to reduce saturation of the core. If the core becomes saturated, the data signal may become "clipped."

Medium voltage power line 120 may be disposed through inductor 602. To facilitate easy installation and minimal impact to customer service, inductor 602 may include a hinge. With such a hinge, inductor 602 may simply snap around medium voltage power line 120 using existing utility tools and techniques. In this manner, installation of inductor 602 can be performed without disrupting power to the power users and without stripping any insulation from medium voltage power line 120.

Inductor 602 is electrically connected to capacitors 606. Capacitors 606 provide some electrical isolation between optoelectronic devices 620, 622 and inductor 602. Capacitors 606 further provide filtering of the power signal from the data signal. That is, the data signal, which typically is a high frequency signal, passes across capacitors 606 while the power signal, which typically is a lower frequency (*e.g.*, 50 or 60 Hz), is substantially prevented from passing across capacitors 606. While such filtering need not be implemented necessarily, filtering typically is included to simplify the design of system. Alternatively, such filtering may be implemented elsewhere within system 200, for example, in transmit circuitry 610, receive circuitry 612, power line bridge 210, and the like.

Capacitors 606 are electrically connected to transmit circuitry 610 and receive circuitry 612. Transmit circuitry 610 and receive circuitry 612 may amplify the data signal, filter the data signal, buffer the data signal, modulate and demodulate the signal, and the like.

Transmit circuitry 610 typically is selected to maximize the power of the data signal to keep the signal-to-noise ratio of the data signal at an acceptable level. Receive circuitry 612 typically includes an amplifier designed to handle the lowest expected received data signal level. At a system level, the modulation and demodulation techniques typically are selected to reduce interference between transmit and receive signals.

Transmit circuitry 610 and receive circuitry 612 are electrically connected to transmit optoelectronic device 620 and receive optoelectronic device 622, respectively. Transmit optoelectronic device 620 converts a light data signal, for example, from communication medium 630 to an electrical data signal for use by transmit circuitry 610. Transmit optoelectronic device 620 may include a light emitting diode, a laser diode, a vertical cavity surface emitting laser, and the like. Receive optoelectronic device 622 converts an electrical data signal from receive circuitry 612 to a light data signal for transmission through communication medium 630. Receive optoelectronic device 622 may include a photosensitive diode, photosensitive transistor, and the like.

Transmit optoelectronic device 620 and receive optoelectronic device 622 are in communication with communication medium 630. As shown, light signals are communicated between both transmit circuitry 610 and receive circuitry 612 and communication medium 630.

Communication medium 630 communicates light signals between power line coupler 100 and the power line bridge 210. Communication medium is electrically non-conductive, thereby breaking the electrically conductive power path between power line coupler 200 and power line bridge 210. Communication medium 630 may include a light pipe, a fiber-optic cable, and the like.

In this manner, data signals on the power lines are converted to light signals and are transmitted over optical communication medium 630. Similarly, light signals from optical communication medium 630 are converted to electrical signals for communication with the power lines. Communication medium 630, being electrically non-conductive, provides the increased safety that is desired by many power distribution companies by not allowing substantial power to flow through communication medium 630.

Power line coupler 200 includes a power supply inductor 680 and a power supply 682. Power supply inductor 680, constructed similar to inductor 602, inductively draws power from medium voltage power line 120. Power supply inductor 680 typically is selected to have magnetic characteristics appropriate for coupling power signals from

medium voltage power line 120. Power supply 682 receives power from inductor 680 (*e.g.*, alternating current (ac) power) and converts the power to an appropriate form for use by transmit circuitry 610, receive circuitry 612, and the like (*e.g.*, direct current (dc) power). As such, power line coupler 200 can be a “closed” system, internally deriving its own power and thereby avoiding the use of batteries (which may be costly and impractical).

Power line coupler 200 includes a housing 650 to protect it from exposure to the environmental conditions. Housing 650 may be constructed with high dielectric, corrosive resistant materials, fasteners, adhesives, and sealed conduit openings. Housing 650 may further be designed to reduce the risk of exposure to the voltage potential present on medium voltage power line 120.

In the embodiment illustrated in Figure 6, communication medium 630 is a fiber optic cable that provides electrical isolation between medium voltage power line 120 and low voltage power line 113. Other communication media may be used to provide such electrical isolation. For example, inductor 602 may include an annularly shaped dielectric material disposed coaxially between medium voltage power line 120 and inductor 602. The dielectric material allows inductor 602 to be magnetically coupled to medium voltage power line 120, thereby allowing communication of data signals. The dielectric material does not allow significant power to pass from medium voltage power line 120 to low voltage power line 113. Alternatively, rather than converting the electric data signals to light data signals, power line coupler 200 may convert the electric data signals to wireless data signals, such as, for example, radio frequency signals.

Figure 7 illustrates another embodiment of a power line coupler 200'. As shown in Figure 7, power line coupler 200' includes a radio frequency (RF) choke 705, capacitors 710, a transformer 720, transmit circuitry 610, receive circuitry 612, transmit optoelectronic device 620, and receive optoelectronic device 622.

RF choke 705 may be disposed around and is directly connected to medium voltage power line 120 and may comprise ferrite beads. RF choke 705 operates as a low pass filter. That is, low frequency signals (*e.g.*, a power signal having a frequency of 50 or 60 Hz) pass through RF choke 705 relatively unimpeded (*i.e.*, RF choke 705 can be modeled as a short circuit to low frequency signals). High frequency signals (*e.g.*, a data signal), however, do not pass through RF choke 705; rather, they are absorbed in RF choke 705 (*i.e.*, RF choke 705 can be modeled as an open circuit to high frequency signals). As such, the voltage across RF choke 705 includes data signals but substantially no power signals. This voltage (*i.e.*, the

voltage across RF choke 705) is applied to transformer 720 via capacitors 710 to receive data signals from medium voltage power line 120. To transmit data signals to medium voltage power line 120, a data signal is applied to transformer 720, which in turn communicates the data signal to RF choke 705 through capacitors 710.

Capacitors 710 provide some electrical isolation between medium voltage power line 120 and transformer 720. Capacitors 710 further provides filtering of stray power signals. That is, the data signal passes across capacitors 710 while any power signal is substantially prevented from passing across capacitors 710. Such filtering can be implemented elsewhere within the system or not implemented at all.

Transformer 720 may operate as a differential transceiver. That is, transformer 720 may operate to repeat data signals received from RF choke 705 to receive circuitry 612 and to repeat data signals received from transmit circuitry 610 to RF choke 705. Transformer 720 also provides some electrical isolation between medium voltage power line 120 and low voltage power line 113.

Capacitors 606 may be electrically connected between transmit circuitry 610 and receive circuitry 612 and transformer 720. Transmit circuitry 610 and receive circuitry 612 are electrically connected to transmit optoelectronic device 620 and receive optoelectronic device 622, respectively. Transmit optoelectronic device 620 and receive optoelectronic device 622 are in communication with communication medium 630. Power line coupler 200' may include a power supply inductor 680, a power supply 682, and a housing 650, similar to that shown in Figure 6.

In the embodiments illustrated in Figures 6 and 7, communication medium 630 is a fiber optic cable that provides electrical power isolation between medium voltage power line 120 and low voltage power line 113. Other communication media may be used to provide such electrical power isolation. For example, inductor 602 may include an annularly shaped dielectric material (not shown) disposed coaxially within inductor 602. The dielectric material allows inductor 602 to be magnetically coupled to medium voltage power line 120, thereby allowing communication of data signals. The dielectric material does not allow significant power to pass from medium voltage power line 120 to low voltage power line 113. Alternatively, inductor 602 may communicate with a wireless transceiver (not shown) that converts data signals to wireless signals. In this case, communication medium 630 is air.

Returning to Figure 2, power line coupler 200 communicates data signals with power line bridge 210, that is turn communicates the data signals to low voltage power line

113. The data signal carried by low voltage power line 113 is then provided to power line interface device 250 via low-voltage premise network 130. Power line interface device 250 is in communication low-voltage premise network 130 and with various premise devices that are capable of communicating over a data network, such as for example, a telephone, a computer, and the like.

Power line interface device 250 converts a signal provided by power line bridge 210 to a form appropriate for communication with premise devices. For example, power line interface device 250 may convert an analog signal to a digital signal for receipt at customer premise 106, and converts a digital signal to an analog signal for data transmitted by customer premise 106.

Power line interface device 250 is located at or near the connection of low voltage power line 113 with customer premise 106. For example, power line interface device 250 may be connected to a load side or supply side of an electrical circuit breaker panel (not shown). Alternatively, power line interface device 250 may be connected to a load side or supply side of an electrical meter (not shown). Therefore, it should be appreciated that power line interface device 250 may be located inside or outside of customer premise 106.

A "web" of wires distributes power and data signals within customer premise 130. The customer draws power on demand by plugging an appliance into a power outlet. In a similar manner, the user may plug power line interface device 250 into a power outlet to digitally connect data appliances to communicate data signals carried by the power wiring. Power line interface device 250 serves as an interface for customer data appliances (not shown) to access data communication system 200. Power line interface device 250 can have a variety of interfaces for customer data appliances. For example, power line interface device 250 can include a RJ-11 Plain Old Telephone Service (POTS) connector, an RS-232 connector, a USB connector, a 10 Base-T connector, and the like. In this manner, a customer can connect a variety of data appliances to data communication system 200. Further, multiple power line interface devices 250 can be plugged into power outlets in the customer premise 130, each power line interface device 250 communicating over the same wiring in customer premise 130.

In alternative embodiments, rather than using low voltage power lines 113 to carry the data signals and power line interface device 250 to convert the data signals, power line bridge 210 converts data signals to be carried by another medium, such as, for example, a wireless link, a telephone line, a cable line, a fiber optic line, and the like.

As described above a customer can access data communication system 200 via power line interface device 250. A service provider, however, typically accesses data communication system 200 via aggregation point 220, as shown in Figure 2. Figure 8 shows more details of aggregation point 220. As shown in Figure 8, power line coupling device 200 communicates between medium voltage power line 120 and aggregation point 220. Aggregation point 220 includes a modem 810, a backhaul interface 820, and a backhaul link 830. Aggregation point 220 allows a service provider to access data communication system 200.

Figure 9 is a flow diagram of an illustrative method 900 for communicating data between medium voltage power line 120 and low voltage power line 113. As shown in Figure 9 at step 910, a data signal is received from medium voltage power line 120. Typically, the data signal is in the form of a high-frequency electrical signal. At step 920, the data signal is converted from an electrical signal to a light signal. At step 930, the light signal is communicated to a fiber optic cable and at step 940, the light signal is received. At step 950 the light signal is converted back to an electric data signal and at step 960, the electric data signal is communicated to medium voltage power line 120.

The invention is directed to a power line coupler and a power line bridge that communicate data signals across a transformer that would otherwise filter the data signals from passing through the transformer. Further, the power line coupler provides high electrical isolation between the transformer primary side and secondary side. The power line coupler can be used to provide data services to residences and service providers. Possible applications include remote utility meter reading, Internet Protocol (IP)-based stereo systems, IP-based video delivery systems, and IP telephony, Internet access, telephony, video conferencing, and video delivery, and the like.

It is to be understood that the foregoing illustrative embodiments have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the invention. Words which have been used herein are words of description and illustration, rather than words of limitation. Further, although the invention has been described herein with reference to particular structure, materials and/or embodiments, the invention is not intended to be limited to the particulars disclosed herein. Rather, the invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. Those skilled in the art, having the benefit of the



teachings of this specification, may affect numerous modifications thereto and changes may be made without departing from the scope and spirit of the invention.

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